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THE DIFFERENCE IN THE PHOTOELECTRIC EFFECT CAUSED BY INCIDENT AND EMERGENT LIGHT.

A DISSERTATION

PRESENTED TO THE

FACULTY OF PRINCETON UNIVERSITY

IN CANDIDACY FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

(DEPARTMENT OF PHYSICS)

BY

OTTO STUHLMANN, Jr.

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From the PHILOSOPHICAL MAGAZINE *for August* 1910.

A Difference in the Photoelectric Effect caused by Incident and Emergent Light.

By OTTO STUHLMANN, Jr., *A.B., Experimental Science Fellow, Princeton University**.

Introduction.

RECENT investigations have shown that the ionization produced by the secondary rays arising from a thin metal plate traversed normally by a primary beam of γ, Röntgen, or β rays, is greater on the emergent than on the incident side.

W. H. Bragg †, in his work on the nature of the γ-rays and Röntgen rays, showed that if γ-rays pass through a thin plate so that the absorption is negligible, the amount of emergent radiation is greater than the incident. This remarkable want of symmetry he points to as appearing fatal to the æther pulse theory of γ-rays and, from their many points of similarity, of the Röntgen rays also. In a later paper on the nature of γ-rays W. H. Bragg and J. P. V. Madsen ‡ also show that this want of symmetry holds for both γ and β-rays. This lack of symmetry for secondary Röntgen rays was also discovered by W. H. Bragg and J. L. Glasson §. They showed that this want of symmetry was in general more pronounced for the softer rays than for hard rays. That the proportion of emergent to incident radiation differed considerably for the different radiators, but was much the same for different thicknesses of screen, except that the proportion tended to increase slightly as the screen was made thicker ; and the tendency was most pronounced in the case of those metals which gave out a quantity of soft secondary radiation, the emergent secondary rays being generally in excess of the incident.

The present experiments were made to see if there was any difference in the photoelectric effect caused by the incident light and the light which emerged after passage through a thin metal film.

Apparatus.

Thin films of platinum were prepared by sputtering *in vacuo* from a platinum cathode on to quartz plates 1 mm. thick. Two plates were sputtered simultaneously so as to insure the same thickness for both films. These were now mounted in the centre of two similar brass cylinders A and B

* Communicated by Prof. O. W. Richardson.

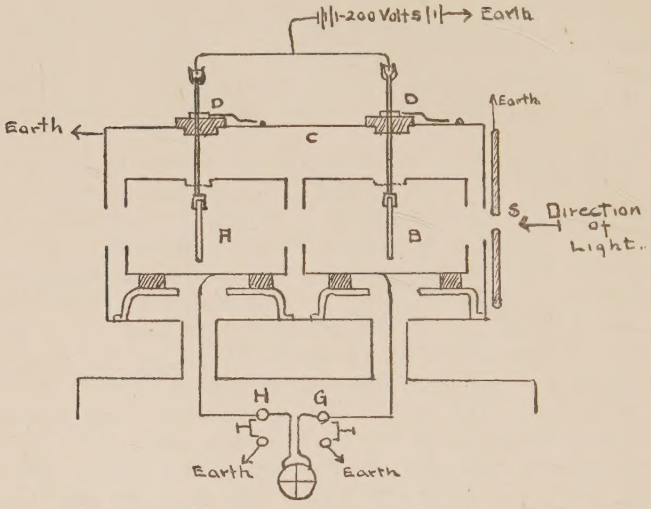
† Bragg, 'Nature,' lxxvii. pp. 270–271, Jan. 23, 1908.

‡ Bragg and Madsen, Phil. Mag. xvi. pp. 918–939, Dec. 1908.

§ Bragg and Glasson, Phil. Mag. xvii. pp. 855–864, June 1909.

(fig. 1), so that their planes were perpendicular to the axes of the cylinders. The plates had an area of one square centimetre, with parallel faces, although not ground optically accurate. The corners were ground round to prevent leakage

Fig. 1.



to the cylinders. They were mounted in brass clamps supported through the top of an earthed metal chamber, C, by means of hard rubber bushings. A pointer, D, attached to the supports, with suitably arranged stops allowed them to be turned around their axes. The plates were connected to the negative terminal of a 200 volt battery, the other terminal of which was grounded. Experiments showed that this was sufficient to produce saturation.

The brass cylinders, 5 cm. long and 2·5 cm. in diameter, were provided with caps the opening through which was 1·5 cm. in diameter. This insured against the possibility of having photoelectric ions drawn over into the adjoining cylinder. The cylinders, resting upon sealing-wax supports, were connected with a Dolezalek electrometer, giving about 900 divisions deflexion per volt, which was placed in an adjoining metal case connected to earth. A narrow beam of ultra-violet light, stopped down to 2 mm. by the opening at S, was allowed to pass down the axes of the two cylinders normally to the plates. An arc, with both rods made of soft iron, running on 4 amp. direct current, was used as the source of ultra-violet light. It was enclosed in a light-tight box provided with a shutter, by which the beam of light passing through the apparatus was controlled. The distance of the arc from the plate B was 55 cm., and from the plate A 60·5 cm.

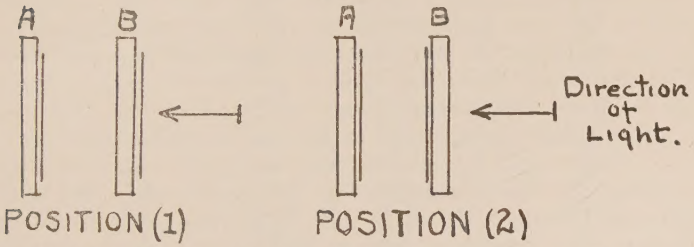
Method of Experimenting.

The saturation current from the illuminated plates to the cylinders could be measured by the following differential method. The keys G, H were opened simultaneously. A beam of light was then thrown on the plates until a measurable deflexion of the electrometer was attained. This deflexion was equal to the difference in the saturation currents from A and B. A was then grounded by connecting G to earth ; the resulting deflexion giving the saturation current from B. The difference between these two readings gave the corresponding reading for A.

The experiment consisted in measuring for various thicknesses of metal films, the saturation current for two successive positions of the plates (fig. 2).

Position (1), A and B so placed that their film side faced the light.

Fig. 2.



Position (2), A with the film side towards the light, and B with the film side away from the light.

Readings were taken alternately for Positions (1) and (2). Thus in every experiment two similar plates with equal thickness of metal films were used, and the ratios of the saturation currents A/B for Positions (1) and (2) successively determined. Hence it is seen that the plate B is always compared for each of the two Positions with plate A. Thus by always referring the measurements to A, the standard plate, the otherwise troublesome variations of intensity of the arc were rendered harmless. Unless the films were very thick it was always found that A/B for Position (1) gave rise to a relatively greater photoelectric effect than the ratio A/B in Position (2), although in the latter case the emergent beam of light was obliged to pass through the quartz plate before affecting the film.

The object of the investigation is the comparison of the ionization due to incident and emergent beams of light of the same intensity. A legitimate way of measuring this intensity is by means of the photoelectric effect such beams

produce. Different observers have shown that beams of similar composition under similar conditions produce a photoelectric effect proportional to the intensity of the light, unless the intensity is very small.

If there were no difference in the photoelectric effect produced by incident and emergent beams of the same intensity, the value of the ratio A/B for Position (1) should always be less than that of A/B in Position (2), on account of the absorption by the quartz plate and by the film. As a matter of fact the reverse was always found to be the case with thin films, showing that the ionization is greater for an emergent than an incident beam of the same intensity. It is not difficult to allow for the absorption by the quartz plate, as will be shown below, but the absorption by the film is a more serious matter. This arises from the fact that these films are so thin that the electrons must be regarded as produced throughout the volume of the film. The method was therefore adopted of seeing if the value of the ratio of the fractions A/B in the two positions did not approach a limiting value, as the thickness of both films was indefinitely diminished. This was found to be the case, as will be seen in the sequel. Under these circumstances one could be certain that the limiting value corresponded to the case in which the absorption of the light by the film was negligible; so that, after allowing for the absorption by the quartz plate, the only difference between the ratio A/B in the two positions in the limiting case will arise from a difference in the ionization produced by incident and emergent beams of equal intensity.

The following table gives a set of readings characteristic

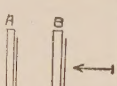
Platinum Set 20.

Position (1).				Position (2).			
B−A.	B.	A.	A/B.	B−A.	B.	A.	A/B.
20·0	76·0	56·0	·736	...	...	...	...
27·0	99·3	72·3	·726	39·0	115·0	76·0	·661
25·0	95·0	70·0	·737	25·0	70·5	45·5	·647
31·0	115·0	84·0	·731	31·0	88·5	57·5	·649
35·0	140·0	105·0	·750	35·2	102·8	67·6	·657
27·0	99·0	72·0	·729	26·0	74·0	48·0	·649
42·0	178·0	136·0	·763	42·0	118·0	76·0	·644
30·0	117·5	87·5	·744	38·0	108·0	70·0	·649
		Average	·739			Average	·651
		Ratio $\frac{(1)}{(2)}$	=1·13				

of the experiments on very thin films of platinum. The maximum deviation from the mean is about 1·5 per cent.

By changing the thickness of the films the following values were obtained:—

Platinum.

No.	(2)= $\frac{A}{B}$ ·	 (1)= $\frac{A}{B}$ ·	Ratio $\frac{(1)}{(2)}$ ·	Log $\frac{B}{A}$ Position (1). Equal to log $\frac{i_0}{i}$.
a	·590	·398	·674	$\bar{1}$·399
b	·652	·726	1·09	·138
c	·651	·739	1·13	·131
d	·587	·617	1·05	·209
e	·647	·708	1·09	·149
f	·573	·656	1·14	·183
g	·531	·552	1·04	·257
h	·534	·536	1·00	·270
i	·624	·694	1·11	·158
j	·632	·657	1·04	·182
k	·632	·708	1·12	·148
l	·644	·730	1·12	·136
1	·534	·536	1·00	·271
2	·628	·696	1·10	·156
3	·635	·679	1·07	·168
4	·639	·719	1·12	·143
5	·622	·677	1·10	·169
6	·549	·578	1·05	·237
7	·550	·475	·863	·323
8	·536	·566	1·05	·247
9	·545	·496	·910	·304
10	·611	·397	·649	·400
11	·660	·394	·600	·404
13	·561	·590	1·05	·228
16	·582	·685	1·17	·164
20	·615	·694	1·13	·158
22	·866	·966	1·11	·015
24	·666	·754	1·13	·122

From the above data we see that the effect is a function of the thickness. It was found impossible to determine the thickness of these very thin films directly. From the ratio of A/B in Position (1) it is possible, however, to compare their relative thicknesses with accuracy. For it is known that when light traverses an absorbing medium the logarithm of the intensity varies as the thickness of the medium traversed. Hence from the preceding arguments it will be seen that values of log B/A Position (1) (equal to log i_0/i) will be proportional to the thickness of the film plus that of the quartz plate used.

Hence a curve (see fig. 3) between the ratio of emergent to incident effect plotted against log i_0/i will be identical in form with that plotted against thickness.

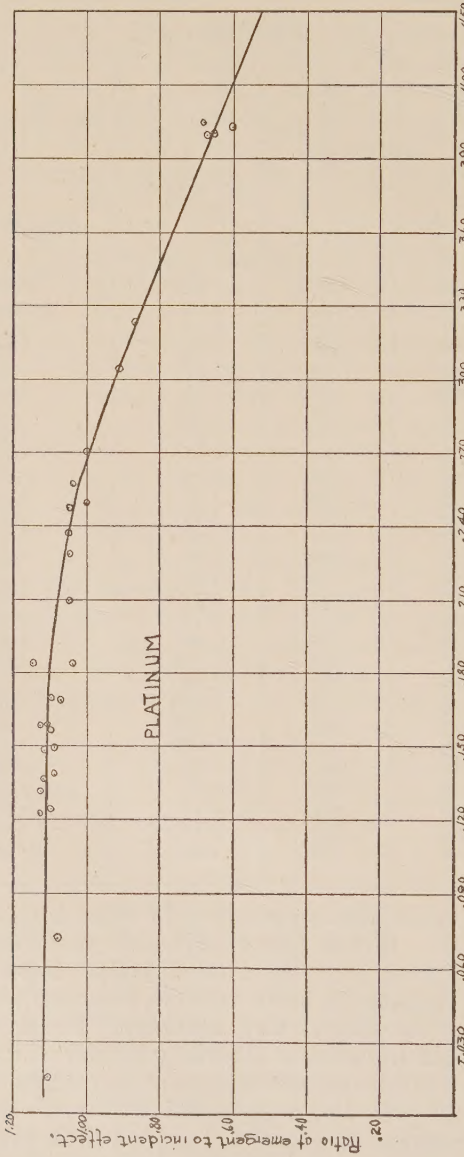


Fig. 3.

It is seen from the curve (fig. 3) that as the metal decreases

in thickness the emergent beam gradually becomes more predominant in its effect, until a certain thickness is reached where the ratio of emergent to incident light attains a constant value 1·12 to 1·0. The ratio remaining constant over so large a range of thicknesses for the thin films of metal, shows conclusively that the absorption of light and electrons by these films as the beam of energy passes through them is negligible, and falls within the experimental error. So that the intensity of the incident and emergent beams must be sensibly equal, and hence the value arrived at above must be a true difference between the incident and emergent light.

Relative Absorption of Quartz Plate.

In order to determine how much of the emergent beam was absorbed by the 1 mm. quartz plates, upon which the films were mounted, the following method was resorted to. A relatively thick film was sputtered on a 1 mm. quartz plate. A thick film was preferably used because less error was involved in the measurement of its photoelectric effect, since for equal intensities of light relatively thicker films gave a larger photoelectric effect per unit time of exposure to the light. With this film the experiments for Position (1) and Position (2) in fig. 2 were repeated, and its ratio of emergent to incident effect noted.

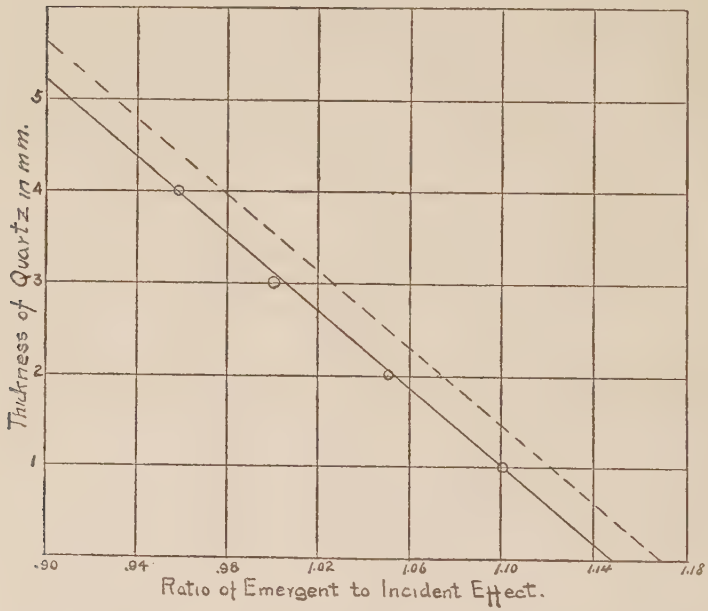
A second blank quartz plate 1 mm. thick was now rigidly fastened to the blank side of the sputtered plate B. So that now the light had to pass through 2 mm. of quartz when the above readings were repeated. This was repeated for 3 and 4 mm. quartz plates by addition of a 2 and 3 mm. plate to the original 1 mm. sputtered plate B.

The results were then plotted as shown in fig. 4 (p. 338). It is seen that for a value of emergent to incident effect for the 1 mm. plate equal to 1·10, a value 1·15 should have been attained if no quartz had been present. So that plotting the curve for 1 mm. quartz equal to 1·12 for very thin films, parallel to the original curve, we get a value for the ratio of the emergent to the incident beam equal to the ratio 1·17 to 1·0, or an increase of 17 per cent.

The above results have been confirmed by reversing the direction of the light. For this purpose a speculum metal mirror was placed so that the reflected beam of light could be alternately sent through the cylinders in opposite directions without changing the position of the plates. Experiments were also made to determine whether a slight deviation

from the normal, on the part of the plates, would affect the results. A change of five degrees in the position of the

Fig. 4.



plates showed no measurable effect. Blank quartz plates placed in the cylinders gave negative results. A test for photoelectric effects arising from scattered light gave no measurable effects, since the aim in the design of the apparatus was to use so small a beam that it cleared all openings in the apparatus and the reflected beams passed out, back through the openings, through which the incident beam entered.

An attempt was made to estimate the absolute value of the thickness of the thin films used, by measuring their resistance. For this purpose "Set 2" of the above data was used. In order to get proper electrical connexions the two opposite edges of the film were silvered by means of the Rochelle Salt Method. Thus a strip of metal film ·78 cm. long and 1 cm. wide was left exposed. Fine copper wire was wound around these edges and electroplated, by means of a copper deposit, to the silver below—thus furnishing a good connexion between the copper wire and the film of

platinum. This was now placed in one arm of a Wheatstone's bridge and its resistance measured. Using a value of the specific resistance for thin platinum films equal to 5×10^{-5} ohm as found by Patterson *, a value for the thickness was found comparable to $\cdot 3 \times 10^{-6}$ cm. Hence the thinnest films used were evidently of order 10^{-7} cm. in thickness. Similar values were found by Patterson for the thinnest films measured by him.

Experiments on other metals are now in progress which will determine the variation of this forward effect with the atomic weight of the element.

Conclusion.

The above experiments show that when beams of ultra-violet light of equal intensity are compared, the ionization they produce is greater on the emergent than on the incident side of a thin platinum film. For a film so thin that the absorption of the light in it is negligible, the ratio of the ionization on the emergent to that on the incident side is as 1·17 is to unity. There is thus an increase of 17 per cent. in favour of the emergent side of the film.

An effect of this kind would obviously be expected on any corpuscular theory of light. It can also be explained on an undulatory theory by a process of the nature of light-pressure, which tends to push the electrons forward in the direction in which the light is propagated. In its ordinary electromagnetic form, however, the undulatory theory does not appear to give rise to effects large enough to explain the phenomena observed. The difficulty appears to be similar to that which arises when the ordinary theory attempts to explain why the ultra-violet light is capable of causing the expulsion of the electrons, with their observed properties, under any circumstances.

This investigation was suggested by Professor O. W. Richardson, and I wish to thank him here for valuable suggestions and advice throughout the course of the work.

Palmer Physical Laboratory,
Princeton University.

* J. Patterson, Phil. Mag. iv. p. 663 (1902).

From the PHILOSOPHICAL MAGAZINE *for December* 1911.

The Difference in the Photoelectric Effect caused by Incident and Emergent Light. Part II.

By OTTO STUHLMANN, Jr., *M.A., Experimental Science Fellow, Princeton University* *.

Introduction.

IN a previous communication † the writers howed that when a beam of ultra-violet light, from an iron arc, impinges on a film of platinum so thin that its absorption can be neglected, the photo-electric effect caused by the emergent beam is greater than the photo-electric effect caused by the incident beam.

Thus for platinum sputtered from a cathode on quartz plates *in vacuo*, the ratio of the emergent photo-electric effect to the incident photo-electric effect was as 1·17 to 1·0, when the absorption of the millimetre quartz plate on which the platinum film was mounted was allowed for.

Shortly after a preliminary account of part of the matter described in the above paper had been published ‡, a notice appeared in 'Nature' by R. D. Kleeman §, who also found that this want of symmetry between the emergent and incident photo-electric effect existed when ultra-violet light fell normally on thin films of platinum sputtered *in vacuo*. By using a rather thick sputtered film of the metal which allowed only 55 per cent. of the incident light to pass through, he found that the ratio of the emergent to the incident photo-electric effect was as 1·15 is to unity, without

* Communicated by Prof. O. W. Richardson.

† O. Stuhlmann, Jr., Phil. Mag. xx. p. 331, Aug. 1910.

‡ Nature, May 12, 1910.

§ Nature, May 19, 1910. Also later Proc. Roy. Soc. A., vol. lxxxiv. (1910).

allowing for the absorption of the film and the 0·3 mm. quartz plate on which the film was mounted.

Had thinner films of platinum been used and allowance been made for the absorption of the light by the quartz, I find that his value would have increased from 1·15 to unity to 1·17 to unity for the ratio of the emergent to the incident photo-electric effect. He repeated his experiments *in vacuo* and found that they checked his previous values when air at atmospheric pressure was in his apparatus.

In view of this work it was thought unnecessary to repeat the above experiments *in vacuo*, since as they stand they are confirmed by Kleeman's results. His measurements were made by an electroscope method which is quite different from the one used in this investigation.

Some years ago Hallwachs * showed that a photo-electric effect could be obtained with a silvered quartz plate when the light was incident through the quartz. This he suggests can be explained in two ways: either the light passes through the silver and liberates electrons at the rear surface of the metal, or the electrons acted on by the light at the incident surface have velocities great enough to carry them out through the rear side. A similar effect was found by Rubens and Ladenburg † with gold-leaf.

They found that the ratio of the photo-electric effect in front and behind was 100 to 1·0, while the fraction of the ultra-violet light transmitted, photo-electrically measured, was one one-thousandth. That they did not and could not have foreseen that the emergent photo-electric effect was greater than the incident effect has been pointed out by Kleeman ‡.

The object of the present investigation is to determine the magnitude of the ratio of the emergent to the incident photo-electric effect for as many characteristically different metals as practicable. In this connexion the phrase photo-electric effect is to be understood as the total electronic emission due to light of standard intensity.

Method of Experimenting.

The same apparatus and method of experimenting was used as in the first paper on this subject §. A beam of ultra-violet light from an iron arc was passed along the common

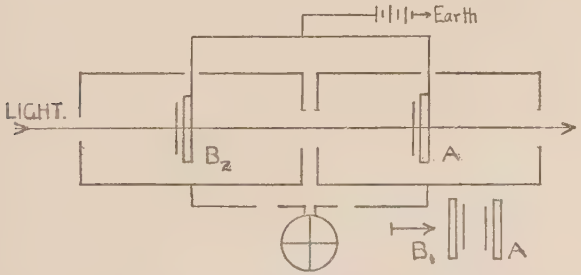
* Hallwachs, *Tagbl. d. Heid. Nat. Ver.* S. 24 (1890).
† Ladenburg, *Deutsch. Phys. Gesell. Verh.* ix. p. 24, § 749–752 (1907).
‡ *Loc. cit.*
§ O. Stuhlmann, Jr., Phil. Mag. xx. p. 333, Aug. 1910.

axis of two brass cylinders placed horizontally end to end. These were insulated from their supports by quartz stays. In the centre of each cylinder perpendicular to the ray, a quartz plate one millimetre in thickness was suspended and was covered on one of its faces with a thin film of the metal under investigation, obtained by sputtering from a cathode *in vacuo*. The films were maintained at a constant negative potential of 200 volts. Each cylinder was connected to one set of quadrants of a Dolezalek electrometer giving 716 divisions deflexion per volt at a scale distance of one metre, with a constant potential of 80 volts on the needle.

It may be of interest to add that a phosphor-bronze strip suspension was used in the electrometer. Any desired sensitiveness could be obtained by gradually reducing the breadth and thickness of the strip by dissolving it away with dilute, warm nitric acid.

The tandem arrangement of mounting the plates (see fig. 1) allowed one to use a differential method. It consisted in measuring for various thicknesses of metal films the saturation current for two successive positions of the plates.

Fig. 1.



The plate A was always maintained stationary with the film side facing the light. The second plate could be rotated about a vertical axis so that the film successively faced towards the light (B_2) and away from the light (B_1).

In the first case the ratio of the ionization $\frac{B_1}{A}$ was measured, giving the ratio of the emergent effect at B to the incident effect at A. In the second case the ratio $\frac{B_2}{A}$ was obtained, giving the ratio of the incident effects for the two plates. Hence the ratio $\frac{B_1}{A}$ to $\frac{B_2}{A}$ gave the value of the ratio of the emergent effect to the incident effect at the same plate B.

This method avoids any difficulties which might be caused by fluctuations in the illumination.

The absorption of the thinnest films became a negligible quantity because the ratio $\frac{B_1}{B_2}$, when plotted against the thickness of the films, approached a limiting value as the thickness was indefinitely diminished. Hence the limiting value corresponds to the case in which the value $\frac{B_1}{B_2}$ arises from a true difference in the ionization produced by emergent and incident light of equal intensity.

Data.

The metals investigated for the difference in the photo-electric effect caused by the incident and the emergent light include magnesium, copper, zinc, silver, tin, platinum *, lead, and iron. In addition selenium, arsenic, and carbon gave unsatisfactory results. Selenium could not be sputtered *in vacuo* owing to its low melting-point. The cathode became distorted, in consequence of heating by the current, before any satisfactory films could be deposited. Carbon gave very satisfactory films of uniform texture, but its photo-electric activities are so small that the results became worthless owing to the fact that the magnitude of the results was never greater than the experimental error.

The above metals were chemically pure and were supplied by Kahlbaum, Berlin, except silver which was commercial "Fine Silver," and was supplied by a local firm.

It was desirable wherever possible to test such metals as exhibited the most diverse chemical and physical properties. Here one is limited by the possibility of sputtering, rapidity of oxidation, lack of photo-electric response and rapidity of fatigue.

The values of the ratios $\frac{B_1}{A}$ and $\frac{B_2}{A}$ obtained for a series of films of different thicknesses and for the metals cited above, are given in the following tables. The third column headed $\frac{B_1}{B_2}$ gives the ratio of $\frac{B_1}{A}$ to $\frac{B_2}{A}$ or the ratio of the emergent photo-electric effect to the incident effect at the same film. The last column gives the values of log $\frac{B_2}{A}$, which is proportional to the optical thickness of the film plus that of the quartz plate used, as was shown in the first paper on this subject.

* For data on platinum see pt. i. *loc. cit.*

Magnesium.

B_1/A.	B_2/A.	B_1/B_2.	Log B_2/A proportional to thickness of film.
1·00	·99+	1·01	·000
1·06	1·02	1·04	·008
1·24	1·19+	1·04	·078
1·15	1·19	·965	·075
1·37	1·32	1·03	·121
1·27	1·34	·948	·127

Copper.

B_1/A.	B_2/A.	B_1/B_2.	Log B_2/A proportional to thickness of film.
1·09	1·07	1·02	·030
1·23	1·17	1·05	·068
1·31	1·24	1·05	·093
1·28	1·24	1·03	·093
1·33+	1·29	1·03	·111
1·31	1·34+	·974	·129
1·37	1·34+	1·02	·129
1·41	1·37	1·03	·137
1·46	1·43	1·02	·155
1·38+	1·54	·904	·188
1·23	1·71	·718	·233
1·25	1·71	·730	·233
1·29	1·76	·732	·246
1·23	1·78+	·689	·252

Zinc.

B_1/A.	B_2/A.	B_1/B_2.	Log B_2/A proportional to thickness of film.
1·20	1·13	1·06	·053
1·33+	1·25+	1·06+	·096
1·38	1·35	1·02	·130
1·45	1·37	1·06	·137
1·52	1·45	1·05	·162
1·71	1·68	1·02	·225
1·53	1·74	·879	·241

Silver.

B_1/A.	B_2/A.	B_1/B_2.	Log B_2/A proportional to thickness of film.
1·18	1·20	·985	·079
1·35	1·33	1·01	·124
1·42	1·41	1·00	·149
1·64	1·66	·987	·220
1·62	1·68	·961	·225

Tin.

B_1/A.	B_2/A.	B_1/B_2.	Log B_2/A proportional to thickness of film.
1·26+	1·16	1·09	·064
1·30	1·20	1·08	·079
1·35	1·21	1·11	·083
1·31	1·20	1·09	·079
1·37	1·29	1·06	·110
1·57	1·43+	1·09	·157
1·65	1·48+	1·11	·171
1·71	1·56	1·09	·193
1·74	1·57	1·11	·196
1·80	1·68	1·07	·225
1·90	1·67+	1·13	·225
1·87	1·68+	1·11	·227
1·81	1·73	1·05	·238
1·79	1·82	·984	·260

Lead.

B_1/A.	B_2/A.	B_1/B_2.	Log B_2/A proportional to thickness of film.
1·12	1·07	1·04	·029
1·23	1·12	1·10	·049
1·19	1·14+	1·04	·057
1·32+	1·24	1·07	·093
1·38	1·25	1·10	·097
1·50	1·51	·995	·179
1·53	1·69	·905	·228

Iron.

B_1/A.	B_2/A.	B_1/B_2.	Log B_2/A proportional to thickness of film.
1·14	1·18	·967	·072
1·21	1·23	·983	·089
1·25	1·28	·976	·107
1·25	1·30	·961	·113
1·26	1·31	·962	·117
1·22	1·45	·841	·161

Fig. 2.

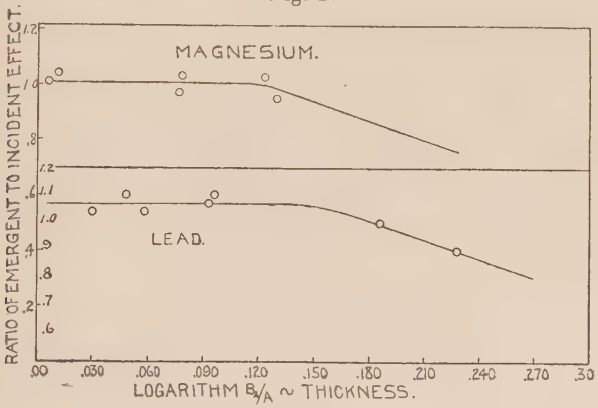
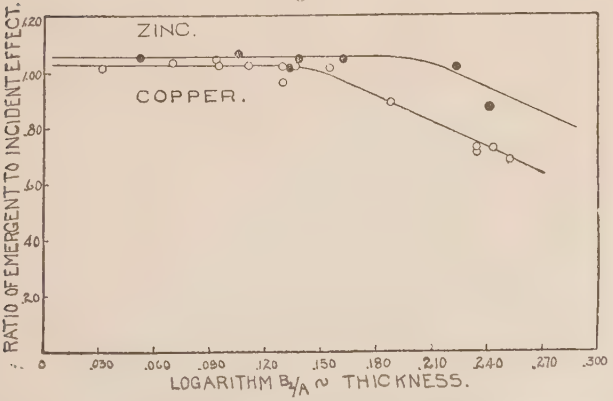


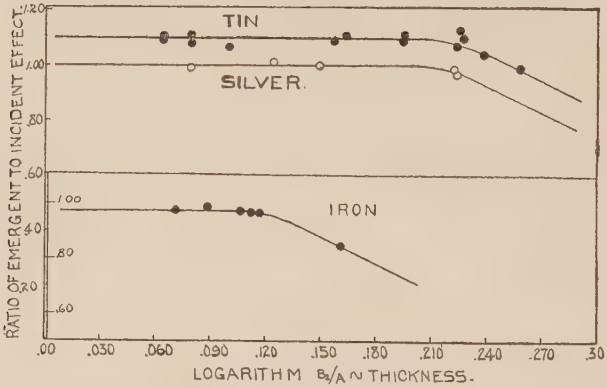
Fig. 3.



Hence a graph (see figs. 2, 3, 4) of the ratio of the emergent

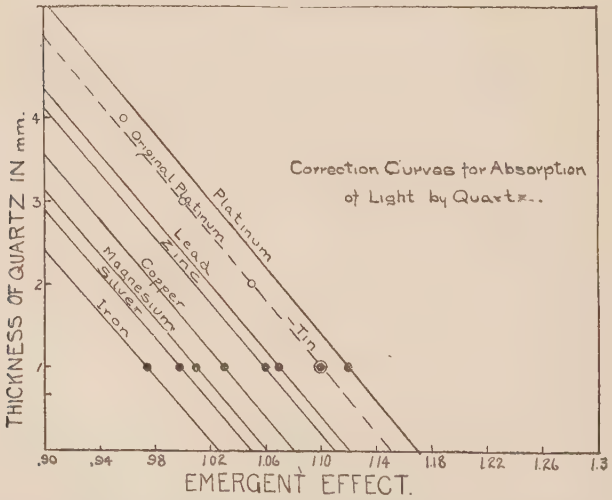
to the incident effect plotted against log B_2/A will be identical in form with that plotted against thickness.

Fig. 4.



It is seen that all the curves possess a common form, such that, as the metal decreases in thickness the emergent beam gradually becomes more prominent in its effect, until a certain thickness is reached where the ratio of the emergent to the incident effect attains a constant value. To this constant value must be added the absorption due to the millimetre

Fig. 5.



quartz plate upon which the metal films are mounted. The corrected values thus obtained * are given in fig. 5.

* For method and data see pt. i. *loc. cit.* p. 338.

The correction curve for tin and the original or uncorrected curve for platinum, upon which experiments were carried on to determine this absorption of the ultra-violet light by the quarz, happen to give identical values. The broken line is here used to call attention to the fact that the original uncorrected curve for platinum and the correction curve for tin are identical.

Conclusions.

If the metals are arranged in the order of their atomic weights and also according to their position in the periodic system as given in the table below, one notices that there is a periodic increase in the ratio of the emergent to the incident photo-electric effect as one ascends through the periods of the table.

	Metal.	Emergent Photo Effect.	At. Wt.	$\frac{\text{Effect.}}{\text{At. Wt.}}$
II. Period	Mg	1·06	24·4	435
III. Period	Fe	1·02+	55·9	183
IV. Period	Cu	1·08	63·6	170
	Zn	1·11	65·3	170
VI. Period	Ag	1·07	107·9	99
	Sn	1·15	118·5	97
VIII. Period	Pt	1·17	194·8	60
IX. Period	Pb	1·12	206·9	54

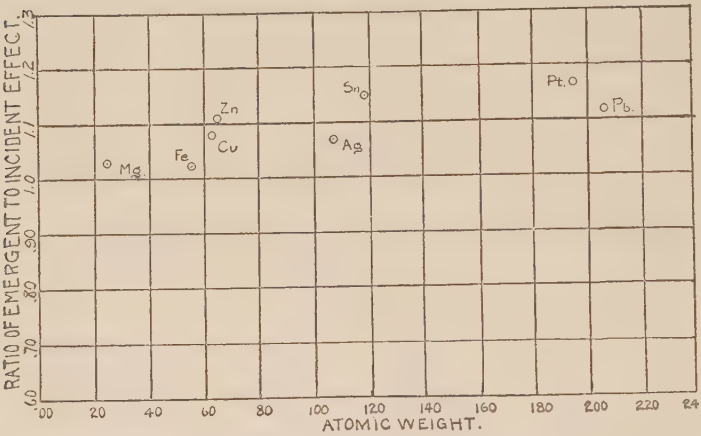
This becomes more apparent when the values for the ratio of emergent to incident photo-electric effect are plotted against their atomic weights as in fig. 6.

Iron, although of a higher atomic weight than magnesium, has a smaller forward effect. The increase in atomic weight from zinc to silver is large, yet the forward effect of silver has very much decreased. The increase in the effect from copper to zinc is about the same as that from silver to tin, while the value for lead, three periods removed, drops to a value nearly equal to that of zinc in the fourth period.

This seemingly points to a periodic variation of the forward effect with the change in the atomic weight, and likewise to a more rapid variation at the end than at the beginning of a period. In the last column of the above table the ratio of the effect to the atomic weight has been tabulated. It will

be observed that the ratio has a constant value in each period. One cannot, however, feel certain that this is a universal law,

Fig. 6.



since it has only been possible to test it in the case of two groups with two elements in each group. Moreover the ratio of the emergent to the incident effect never differs much from unity and there is no very great difference in the values of the atomic weights of the elements in a given group. Thus the range of possible variation is rather restricted.

Since it is known that the incident photo-electric effect increases with decreasing wave-length of the incident light, it may be that the ratio of the emergent to the incident effect would be constant for monochromatic light, so that the present variations in the above ratio of emergent to incident effect for the various metals might be attributed to a selective photo-electric activity on part of the films used. For instance, platinum might respond photo-electrically more easily to shorter wave-lengths than magnesium and hence give a greater value for the ratio of the emergent to the incident effect. At any rate this is a possibility which should be carefully investigated. For this reason the investigation will be continued with the object of determining the value of the above ratios for variations with the wave-length of the incident light.

From the existence of similar effects to those here described, in the case of the γ-rays and Röntgen rays, Bragg has concluded that these radiations are of a corpuscular character.

The results of the present experiments indicate that that part of Bragg's argument applies with equal force to the case of the radiations which produce the photo-electric effect. Since the photo-electric effect can be produced with visible light in the case of sufficiently electro-positive metals, and since there is a continuous gradation between such cases and the effects here investigated, there seems to be no valid reason for supposing that the difference between the emergent and incident effect is not characteristic of both ordinary and ultra-violet light as well as the more penetrating radiations examined by Bragg. If it stood alone this investigation would be a strong argument in favour of the unitary theory of light. The objections to such theories on other and apparently more fundamental grounds are very serious, as Lorentz has recently shown. Under the circumstances it seems desirable to postpone further discussion pending the accumulation of more experimental evidence.

This subject and its method of investigation was suggested by Prof. O. W. Richardson and carried to its present stage under his direction. I wish to thank him here for his valuable assistance, advice, and encouragement throughout the course of this work.

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